PROGRESS TOWARDS AN MCT-BASED 100+ KW HIGH-FREQUENCY INVERTER

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Abstract

Significant progress has been recently made in achieving a 100+ kW level inverter using high-voltage diffusion-doped MOS Controlled Thyristors (MCTs). These MCTs are the deliverables from a three year contractual effort to extend the MCT technology to devices capable of switching high voltages/powers. Preliminary test results have shown that a single device can control/turn-off at least 160 kW average power (burst), handle a surge (single shot) turn-on of 15.5 kA at 1720 V for a peak switched power of 26 MW, and can be operated up to 50 kHz. Additionally, series operation of 3 MCTs to 5 kV, and parallel operation of 3 MCTs to 300 A turn-off have been demonstrated. Future work will deal with construction and evaluation of a high average power inverter using these MCT switches.

Introduction

Inverters and converters are well-known circuits and used in many different power applications from motor control to DC-DC conversion. For applications such as tactical (mobile) military systems, space platforms, and various industrial/commercial needs there is a premium on decreasing the size and weight, and increasing the efficiency. The MOS Controlled Thyristors (MCTs) is a new kind of power turn-off device which is a candidate for consideration here due to its high efficiency, relatively fast switching speed, ease of gate drive, and high turn-off current density.

High-voltage MCTs are the result of a three year contract placed by the Electronics Technology and Devices Laboratory (ETDL) with General Electric Center for Research and Development (Figures 1 and 2). These devices differ from the (near) commercial epitaxial MCTs in that the junctions and MOSFET cells are diffused into a high resistivity wafer of float zone silicon, rather than being grown on an epitaxial layer. The basic starting material and processing for the high-voltage MCTs is the same kind as that of power SCRs and GTOs, which have voltage ratings up to 8 kV. The first deliverables of high voltage MCTs have a blocking voltage up to 3 kV, and can go higher, whereas epitaxial MCTs are constrained to less than ~1.7 kV by the limits of the process technology of growing uniform epitaxial layers.

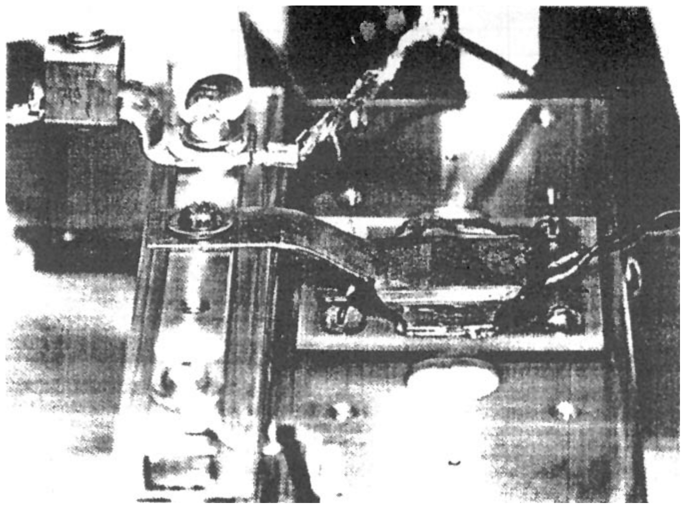

Figure 1. A high-voltage diffusion-doped MCT switch. Typical specifications: 2.5 kV blocking voltage, 200 A turn off, 1 cm^2 active area die, 0.3 μs risetime, 4 μs falltime.

At ETDL we have been involved in extensive test and evaluation of these high-voltage MCT deliverables for the past few months.[1] Recently, as we have gained experience in understanding the limits of these devices, we have begun work in building sub-modules of series, parallel, and series/parallel arrays of switches to handle higher powers. We are now directing our efforts towards evaluating these devices in power applications such as a high average power inverter and an electric gun switch.

By operating an inverter at relatively high frequency (~ 20 kHz) several key advantages can be realized including reduction of the size/weight of magnetics and ability to respond very quickly to source and load changes. NASA has extensively studied high-frequency AC power distribution architecture[2] for use on the space station. Similarly, Westinghouse Electronic Systems Group in Baltimore is producing an advanced ultra-compact DC-DC converter for aerospace applications using epitaxial MCTs. They have built a 10 kW module operating at 100 kHz with a power density of 6.1 W/cm^3 and an overall efficiency of 95%. A parametric study by General Atomics determined the optimal frequency range to operate a high power inverter (> 20 kW) was from 20 to 40 kHz.[3]

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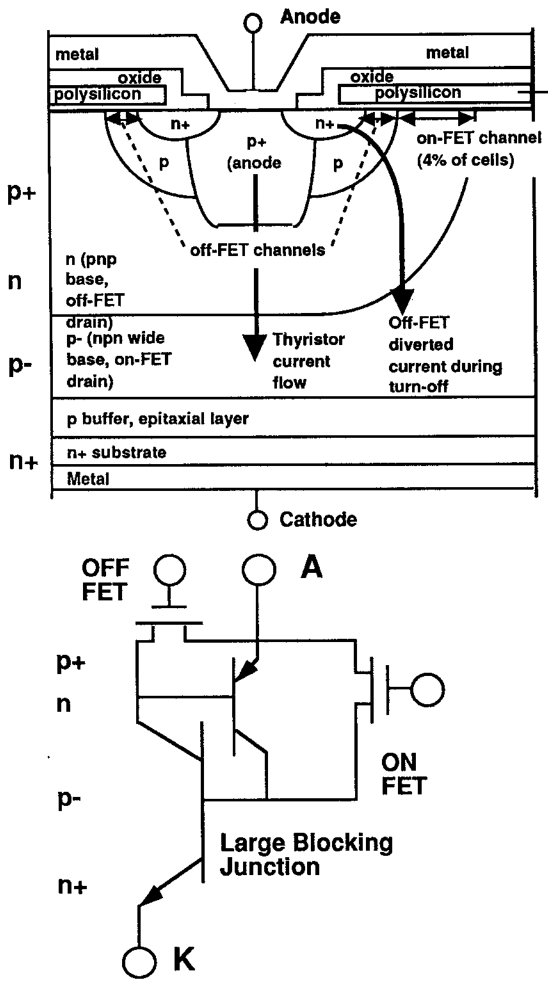

Figure 2. A cross section of an MCT control cell (20 µm repeat length) and an equivalent circuit.

Inverter Concept and Goals

Our proof-of-principle inverter is targeted at demonstrating the relative merits of MOS Controlled Thyristors in an application that is typical of electric vehicle drive and power conditioning needs of the Army. Our approach is to construct a 100+ kW average power inverter testbed, operate this under typical load conditions (i.e., motors, DC conversion), and examine the performance of the switches over a frequency range of 400 Hz to 50 kHz. The performance of the MCTs in this inverter will be directly compared, where possible, to that of other devices including GTOs, IGBTs, and other power switches.

Shown on Figure 3 is a circuit for a simple inverter which will be a starting basis for our testbed. Since the MCT switches can handle an extremely high turn-on current density, in comparison to their turn-off current density, we will investigate other inverter configurations, such as a series-resonant or a quasi-resonant, which make use of this ability.

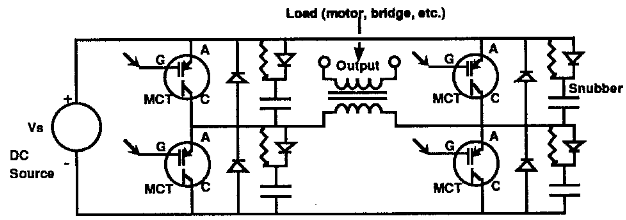

Figure 3. A simple, baseline inverter circuit configuration.

We plan to examine in detail the system operation, switching power losses, efficiency, and possible failure modes along with the analysis of the dynamic current and voltage sharing among the switches. There is some concern about stable operation in paralleling devices which will be investigated.

Recent Progress

In another paper in this conference[1] we discuss the characterization of the high voltage MCT devices. That work has demonstrated a single MCT can turn off (with a snubber) 1700 V at 150 amps, and a surge turn on (single shot) capability of at least 15.5 kA - corresponding to a switched power of about 26 megawatts. Additionally, we have operated three high-voltage MCT switches in series at 5 kV and 150 A turn-off, and three devices in parallel at 300 A total with good current sharing.

As discussed previously, it is important to be able to operate an inverter in the high frequency (20-40 kHz) range. Shown on Figure 4 is the test circuit, and on Figure 5 the waveforms for operation of a high-voltage MCT at 50 kHz at an average power level of 157 kW. This "average" power was only for a short burst due to cooling and power supply limitations; we are in the process of upgrading our testbed. Because of substantial switching losses (turn-off) the efficiency was only 92.1%. Shown on Figure 6 are the waveforms for operation at 20 kHz and 160 kW; here the efficiency is 96.1%.

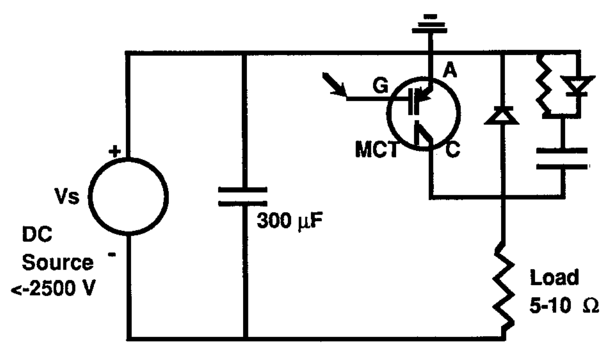

Figure 4. Test circuit for high voltage MCTs operation.

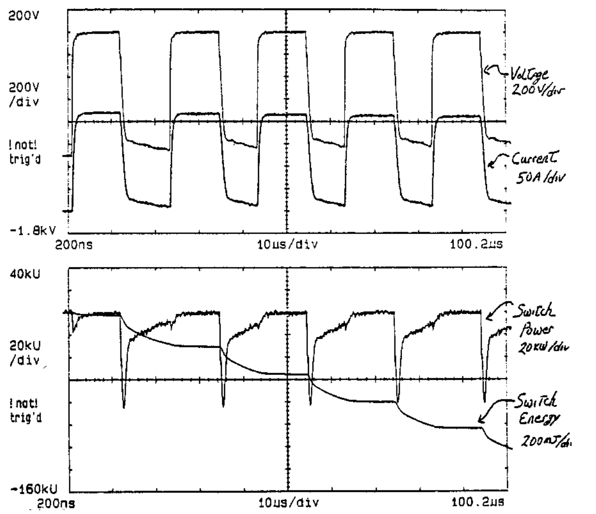

Figure 5. MCT device voltage and current waveforms for 50.2 kHz operation.

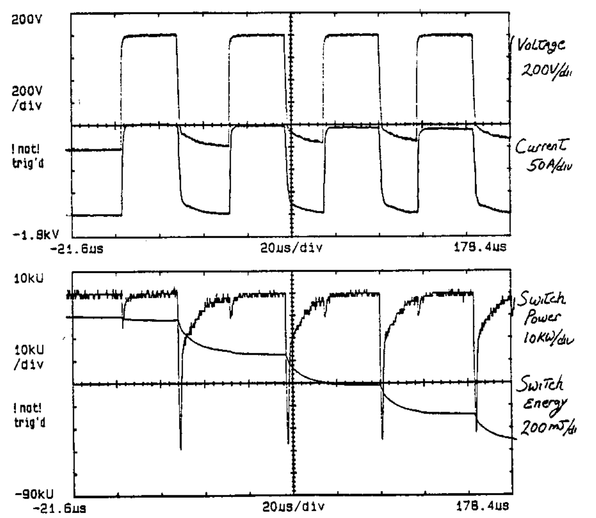

Figure 6. MCT device voltage and current waveforms for 23.2 kHz operation.

These data are remarkable since they show that the first prototype high-voltage MCT switches are capable of handling high average powers at high switching frequencies with good efficiencies. Development of future high-voltage MCTs which are more capable and more efficient is underway by the Electric Power Research Institute.

The efficiency of the MCT switch as a function of switching frequency is shown on Figure 7. Over a range of 5 kHz to 50.2 kHz the switching efficiency varied from 98.9% to 92.1%, respectively. At an average power of 150 kW at 50 Khz, this would result in a power dissipation of about 12 kW into the switch - an impossible requirement for cooling for a die area of 1 cm^2. The rather large turn-off losses in these prototype MCT devices is due to a long tail, caused by slow recombination of charge in the wide blocking junction, and suggests that a faster/more efficient switch is needed.

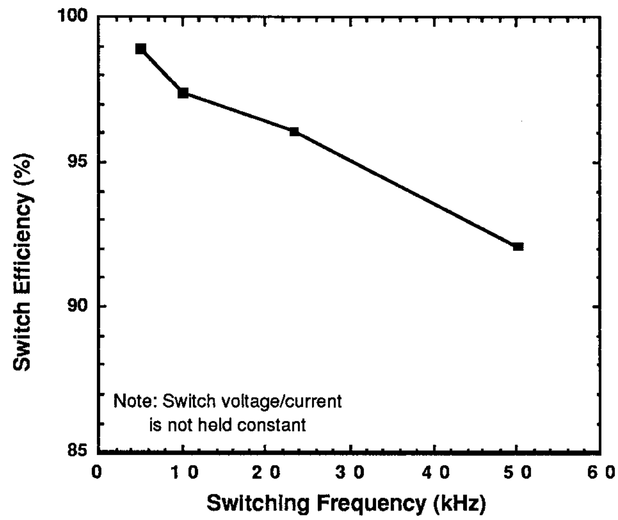

Figure 7. Efficiency of switching for a high-voltage MCT from 5-50 kHz.

Summary

We are well along the way in developing a high average power inverter testbed using high-voltage diffusion-doped MOS Controlled Thyristors (MCTs). Operation of these MCTs at the power, frequency, and efficiency levels required for such an inverter has been demonstrated. Preliminary test results have shown that a single device can control/turn-off at least 160 kW average power (burst), handle a surge (single shot) turn-on of 15.5 kA at 1720 V for a peak switched power of 26 MW, and that operation up to 50 kHz is feasible. Additionally, series operation of 3 MCTs to 5 kV, and parallel operation of 3 MCTs to 300 A turn-off have been demonstrated.

The next step will involve constructing an inverter testbed capable of supplying sufficient power and cooling for continuous high average power work. We will investigate various inverter configurations, including resonant and quasi-resonant circuits, to make the best use of the characteristics of the MCT switch. A detailed analysis of the MCT operation and comparisons to other power devices will be made.

References

1 R. Pastore, C. Braun, M. Weiner, "Characterization of 3000 Volt MOS Controlled Thyristors," Proceedings of the 8th IEEE Pulse Power Conference, June 1991.

2 NASA Workshop on High Frequency Power Distribution and Controls Technology, Cleveland, Ohio, June 1991

3 A. Nerem, C. B. Baxi, R. J. Callanan, W. G. Homeyer, R. J. Thibodeaux, "High-Power Converters for Military and Space Programs," General Atomics internal report GA-A20147, Air Forced contract F33615-87-C2717, August 1990